HYDRAULICS OF PERFORATED TERRACE INLET RISERS

by

KARL KENTON VISSER

B. S., Kansas State University, 1982

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE in Agricultural Engineering

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

Approved by:

James Steichen
Major Professor

ACKNOWLEDGEMENTS

The author wishes to acknowledge those who have assisted the research in some way. Several Soil Conservation Service (SCS) employees deserve recognition. Paul Kleppe, SCS technician in Hiawatha, Kansas, first introduced the author to the field application of designing perforated terrace inlet risers. Frank Kinsey, retired SCS area engineer in Manhattan, Kansas, stimulated the author to pursue this investigiation into riser performance and design equations. Charles Gentry, SCS area conservationist in Manhattan, Kansas, encouraged the pursuit of graduate studies.

Within the Kansas State University Agricultural Engineering Department, additional help was forthcoming. Darrel Oard, laboratory technician, assisted in modifying the flume for this testing. Jian Hua, graduate student, deserves special recognition for his generousity in providing additional data on two risers. Dr. James Steichen, associate professor, was very encouraging during the prolonged writing of this thesis. Dr. Bruce McEnroe, assistant professor of Civil Engineering at Kansas State University, instructed and guided the author on the hydraulic aspects of the research.

Finally, thanks goes to my wife, Susan, for her prayers and positive reassurance throughout the research and writing of the thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Underground outlet terraces have developed as a permanent fixture in the conservation picture. Caldwell (1985) states that, in some areas of the country, "virtually all terraces are constructed with underground outlets." In the field, questions have arisen regarding the adequacy of riser design. This research was undertaken as a way to answer some of those questions. Do risers behave as predicted by simple modification of the orifice equation? Does the flow through each hole behave as submerged orifice flow or free discharge flow? Present design of perforated terrace inlet risers seems to be governed by assumptions and a lack of thorough laboratory research.

LITERATURE REVIEW

Flow through a single orifice can be analyzed by Bernoulli's equation by incorporating a discharge coefficient to account for the contraction of the jet. The result is the general orifice equation:

$$Q = c\ A\ (2\ g\ H)^{0.5} \tag{1}$$

Q - discharge
c - orifice coefficient of discharge
A - orifice area
g - acceleration of gravity
H - orifice head

Most investigators have assumed that a vertical perforated riser will perform as a simple sum of many orifices with varying heads. In other words, the flow into each hole in the riser has negligible effect on the flow into any adjacent hole. Another assumption is that the head to be used in computing the flow for each orifice is the difference between the water surface outside the riser and centerline of the orifice. This means that the hole is behaving as an unsubmerged orifice, as shown in Figure 1.

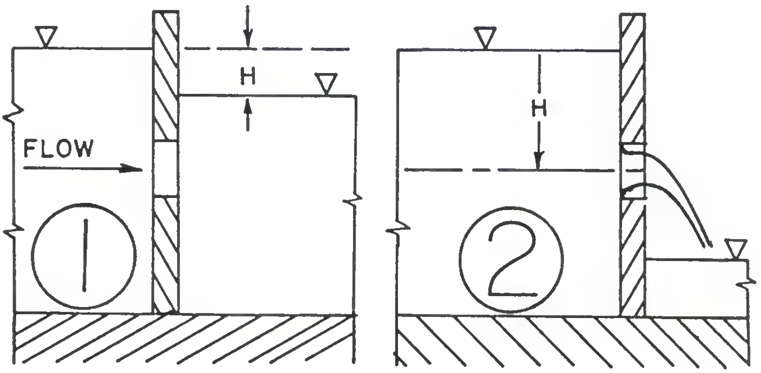


Figure 1. Schematic of Submerged (1) and Unsubmerged (2) Orifice Flow

The reality of this latter assumption depends on the conditions inside the riser. Also, if the inside of the riser is not ventilated to atmospheric pressure, the additional pressure differential could increase the discharge at any given head. This increase in discharge could be accounted for by any increase in the discharge coefficient. Generally, the coefficient of discharge is taken to be approximately 0.6 for a sharp-edged orifice. As the entrance becomes more rounded, the value of the coefficient increases.

A look at existing riser design formulae would be helpful. Beasley et al. (1984) presented an equation for calculating the required number of holes for any given discharge, water depth, and hole size. The holes are assumed to be equally spaced.

$$N = 0.56\ Q\ /\ (\ a\ (H)^{0.5})\qquad \text{(SI units)}\qquad (2)$$

$$(N = 0.30\ Q\ /\ (\ a\ (H)^{0.5})\ )\qquad \text{(English units)}\qquad (3)$$

N - number of holes required
Q - peak flow through the riser, m^3/s (ft^3/s)
a - area of each hole, m^2 (ft^2)
H - depth of water in the terrace channel, m (ft)

It is a rather enlightening exercise to begin with Equation (1) and derive equations (2) and (3). The mathematical proof follows:

$$dQ = c\ dA\ (2\ g\ h)^{0.5}\qquad (4)$$

$$dA/dh = a\ n\qquad (5)$$

$$dA = a\ n\ dh\qquad (6)$$

$$dQ = c\ (a\ n\ dh)\ (2\ g\ h)^{0.5}\qquad (7)$$

$$dQ = \{c\ a\ n\ (2\ g)^{0.5}\}\ h^{0.5}\ dh\qquad (8)$$

Integrate (8) from h = 0 to h = H.

$$Q = \{c\ a\ n\ (2\ g)^{0.5}\}\ H^{1.5}/1.5\qquad (9)$$

$$Q = \{c\ a\ (2\ g)^{0.5}\}\ (n\ H)\ (H^{0.5}/1.5) \tag{10}$$

$$(n\ H) = Q\ /\ \{c\ a\ (2\ g)^{0.5}\ (H^{0.5}/1.5) \tag{11}$$

$$N = 1.5\ Q\ /\ \{c\ a\ (2\ g)^{0.5}\ (H^{0.5})\} \tag{12}$$

a - area of each orifice
A - total area of all orifices
c - orifice coefficient of discharge
g - acceleration of gravity
h - head
H - total head
n - holes per unit depth
N - total number of holes at head = H
Q - discharge

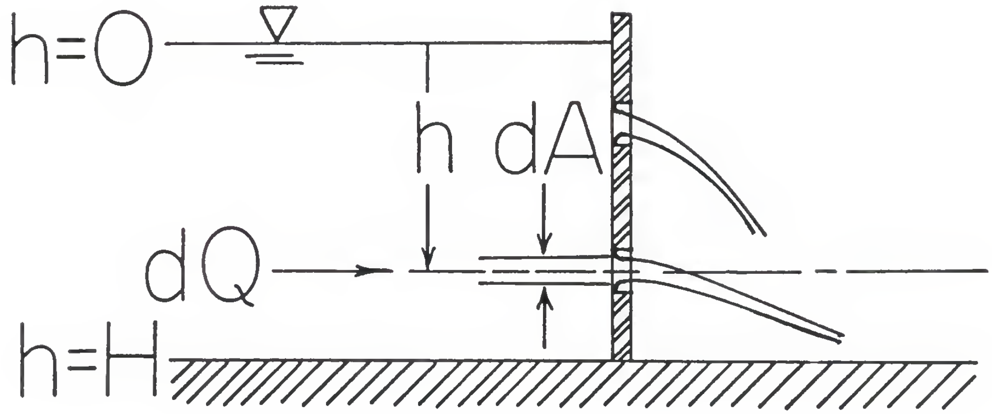


Figure 2. Schematic Showing Notation Used in Equations (4)-(12)

Substituting a value of 0.6 for c and the correct units for the acceleration of gravity into (12) will yield (2) and (3).

A key assumption for this equation is that all the orifices have free discharge. If the flow for any orifice(s) actually is submerged, the head would decrease and the flow would decrease also. Conversely, if the flow inside the riser was not ventilated to the atmosphere, then the flow for any given head could be increased.

In Kansas, the Soil Conservation Service (1979) has developed a chart for computing riser discharge. The primary equation of interest is:

$$Q = c\ A\ (2\ g\ (0.7\ H))^{0.5} \tag{13}$$

Q - total discharge
c - orifice coefficient of discharge
A - total area of all orifices
g - acceleration of gravity
H - water depth in the terrace channel

The chart (SCS,1979) does not show how the head computation is derived, so one can only guess at its derivation.

Again, the assumption for free discharge is fundamental for the accuracy of the equation. If the flow were submerged at the bottom orifices, then the head would decrease for those holes and the flow would correspondingly decrease.

Equations (9) and (13) both attempt to model riser discharge. However, the computed discharge from Equation (13) will be about 25% greater than the discharge from Equation (10), for the same coefficient of discharge.

The SCS chart does place a limit on the application of the Equation (13). The computed riser flow must pass through the riser down to the buried underground outlet line. Therefore, the capacity of the riser holes is checked against the capacity of a horizontal orifice of the riser diameter at a given distance below the terrace channel. Equation (14) is the limit discussed above for the application of Equation (13) in riser design.

$$Q = c\ A\ (2\ g\ (0.7H + k)^{0.5} \qquad (14)$$

Q - discharge, m^3/s (ft^3/s)
c - orifice coefficient of discharge, 0.6
A - total area of all orifices, m^2 (ft^2)
g - acceleration of gravity 9.81 m/s^2 (32.2 ft/s^2)
H - water depth in the terrace channel, m (ft)
k - recommended minimum depth of cover over conduit, 0.61 m (2 ft)

This limiting flow regime check is probably adapted from techniques commonly used when designing drop inlet risers for dams. The limiting flow Equation (14) listed above, however, is apparently of empirical origin. It is beyond the scope of this research to fully examine it.

Neither the SCS charts (1979) nor Beasley et al. (1984) give reference to any laboratory testing to bear out the assumptions used. At least one group of researchers have made measurements of the performance of actual perforated risers. Linderman et al. (1976) tested debris basins in cattle feedlots and developed empirical equations for riser design. For example, Equation (15) is for a riser with 16 mm (0.63 in) diameter holes.

$$Q = (21.6/n)\ H^{1.43} \tag{15}$$

Q - discharge, m^3/min
n - spacing between hole centerlines, mm/hole
H - water depth in the debris basin outside the riser, m

The Beasley et al. (1984) equation can be transformed to a very similar form, namely:

$$Q = (21.0/n)\ H^{1.5} \tag{16}$$

Q - discharge, m^3/min
n - spacing between hole centerlines, mm/hole
H - water depth in the debris basin outside the riser, m

Equation (16) was developed by taking the orifice coefficient of discharge to be 0.6.

The exponent on the head (H) is greater in the theoretical Equation (16). One would expect to see the discharge expressed as a function of the head to the 1.5 power. The empirical Equation (15) is within five percent of the sum of orifice flows for the range of hole spacing 20 to 40 mm and heads from 0.1 to 1.0 m (Linderman et al., 1976).

Mielke (1985) equipped some water and sediment control basins with continuously recording water-level recorders. The primary interest of this research was the performance of the basins and little mention is made of actual riser performance. The risers also were installed with horizontal orifice plates, which would greatly affect riser discharge.

Finally, a riser manufacturer was asked if testing had been performed on risers. Mark Hickenbottom of Hickenbottom, Incorporated, said that he did not know of any testing done. He said that the risers were designed theoretically, not with test data.

INVESTIGATION

Objectives

The objectives of the the research were fourfold. First, determine the coefficient of discharge for a hole in a curved surface, similar to a riser. Second, gather laboratory data for generating a stage-discharge curve for each of the three different risers over typical design depths (0.2 to 0.8 m, 0.5 to 2.5 ft). Third, develop equations to describe the stage-discharge data generated. Finally, of primary interest, compare the data against current design criteria in use.

Materials and Equipment

The three different risers used in testing are of primary importance and deserve detailed description. Figure 3 shows schematic representations of the risers used.

Two risers were fabricated in the laboratory from 150-mm (6-in) diameter cast acrylic tubing with a wall thickness of 3 mm (1/8 in). Cast acrylic was chosen for its transparency so flow conditions inside the riser could be observed. Risers are usually fabricated from PVC pipe with nominal diameters of 100 mm (4 in) to 250 mm (10 in). The 150-mm (6-in) diameter is representative of common practice.

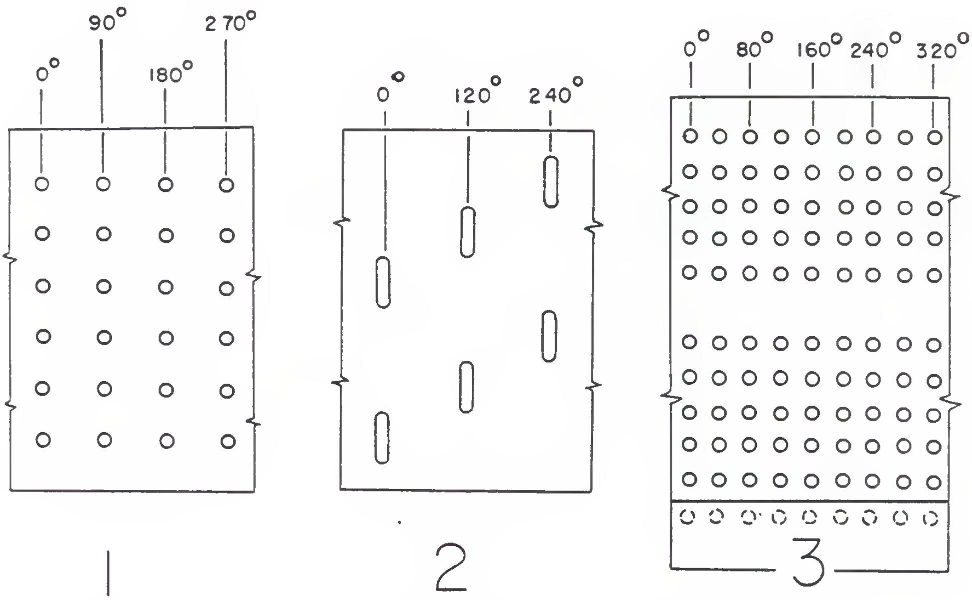


Figure 3. Schematic Representations of Risers
1 - Round-Hole Riser
2 - Slotted Riser
3 - Hickenbottom Riser

The first cast acrylic riser was drilled with a row of four 25-mm (1-in) diameter holes every 76 mm (3 in). Each hole in any horizontal ring of four holes was 90° from the next hole.

The second cast acrylic riser had slots with rounded ends every 102 mm (4 in) on center. Each slot was 25 mm (1 in) wide and 102 mm (4 in) high. The slots were located around the riser circumference in spiral staircase fashion. The vertical centerline of each slot was 120° from the next. Both risers were about 0.9 m (3 ft) tall.

The third riser was a commercially manufactured riser from Hickenbottom, Inc. of Fairfield, Iowa. The 150-mm (6-in) nominal diameter riser had one horizontal row of holes spaced every 67 mm (2.6 in) along its vertical axis. The vertical distance, however, between the fifth and sixth horizontal row of holes was double the normal spacing. Each row consisted of 9 holes of 25-mm (1-in) diameter equally spaced around the circumference of the riser. This riser was also approximately 0.9 m (3 ft) tall. See Figures 8-11 and 14-16 in the Appendix for pictures of and more data on the risers.

The largest single piece of equipment used was the flume in the Kansas State University hydraulics laboratory. The flume is approximately 0.8 m (31 in) wide and 17.4 m (57 ft) long. The sides of the flume are 1.2 m (4 ft) high. The flume was chosen because it was an existing structure and could recirculate the water used. Other arrangements of equipment were considered but would have required much more fabrication or modification time than the flume. The description of other laboratory equipment will follow along with the schematic drawing of Figure 4.

Flow entering the flume was separated from the riser area by a set of wooden baffles. Beyond these, the riser depth point gauge was mounted 0.74 m (29 in) from the nearest edge of the riser. This depth gauge is shown in Figure 10 in the Appendix. The depth of water around the riser was taken to be the elevation difference between the water surface at any time and the water surface when flow ceased going through the bottom hole of the riser. The elevation of the no-flow condition for each riser was different. Therefore, several different measurements were taken on each riser to determine the elevation of the bottom of the lowest perforation.

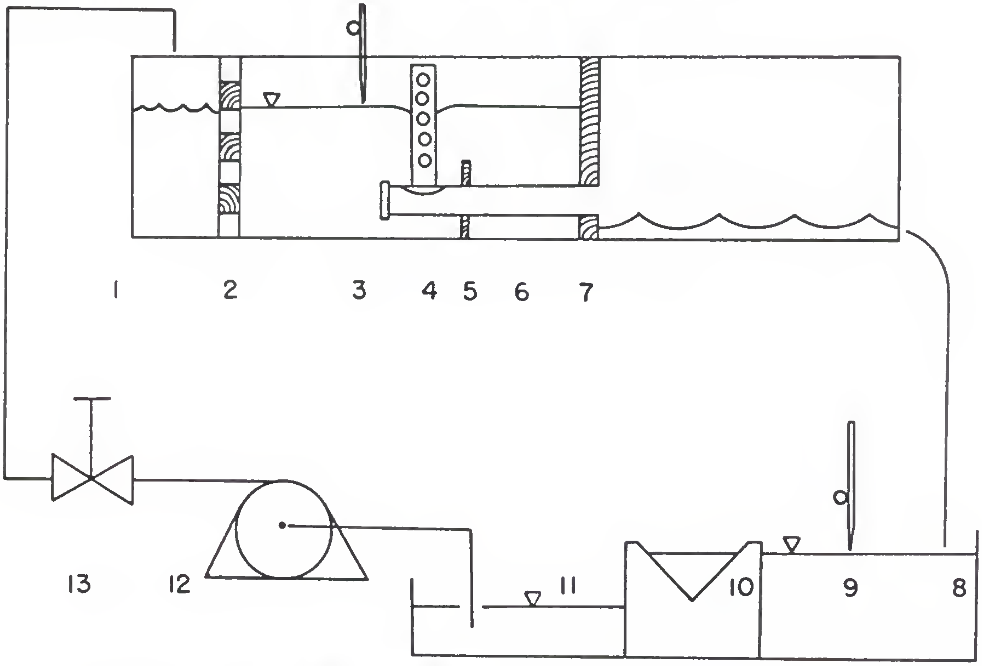


Figure 4. Equipment Schematic

1. Flume
2. Baffle
3. Riser Depth Point Gauge
4. Riser
5. Plywood Brace
6. PVC Outlet Pipe
7. Plywood Check Gate
8. Return Trough
9. Weir Depth Point Gauge
10. Std. 90^{o} V-notch Weir
11. Sump
12. Pump
13. Valve

The risers fit inside a PVC saddle. The Hickenbottom riser fit snugly into the saddle. The two cast acrylic risers fit loosely, so the annular space was filled with rubber gasket material. All the risers were then sealed with gray weatherstrip caulking at the seam between the saddle and riser.

The saddle was secured to a 0.25 m (10 in) diameter PVC outlet pipe less than 3 m (10 ft) long. The outlet pipe was deliberately oversized, so that the limiting factor to the flow would be the perforated riser, not the outlet pipe. Typically, the outlet tube flow depth was no more than one-third to one-half of the pipe diameter, measured at the exit.

Immediately downstream of the saddle was the first plywood support brace. This brace provided lateral and vertical constraint for the outlet tube and riser. The second brace, on the downstream end of the outlet tube, also acted as a check gate as well as a support. It is interesting to note that when submerged, the outlet tube exerted a large upward force. This force is equal to the weight of displaced volume of 0.15 m^3 (5.5 ft^3) of water. Beyond the outlet tube, the water flowed back onto the floor of the flume for about 10 m (30 ft). The depth of flow in the flume was approximately 50 mm (2 in).

From the flume, the water dropped 2 m (6 ft) into a return trough in the floor of the laboratory. Baffles were again placed in the flow to minimize depth fluctuation. The slope of the trough is 0.5 percent and the trough is 0.86 m (34 in) wide. Another point gauge was set up to measure the head for the standard 90° V-notch weir. This point gauge required a stilling well that was fabricated out of a section of 0.25-m (10-in) diameter PVC pipe. Figure 12 in the Appendix shows the weir depth point gauge and stilling well. The weir depth point gauge was 3.5 m (11.4 ft) upstream of the weir. The invert of the weir was 0.3 m (12 in) above the trough floor and the top edge of the weir was 0.3 m (12 in) above the invert. The weir flow remained free and unsubmerged at all discharges. The V-notch weir met the requirements for a standard weir (Bos, 1976). The water flowed from the weir into a sump, where the water was ready to be recirculated by the pump.

The primary factor limiting discharge was the depth of the return trough. Secondarily, the sides of the flume only allowed riser depths of 760 mm (2.5 ft). Some freeboard and the outlet tube occupied the rest of the flume depth.

A brief description of the apparatus used to calibrate the discharge coefficient is also warranted. A large metal tank approximately 1 m x 1 m x 1 m (3 ft x 3 ft x 3 ft) was equipped with a small slot at the top of the tank. A section of the 150-mm (6-in) cast acrylic tubing was drilled with one 25-mm (1-in) diameter hole. This riser section was then fit into the small slot in the tank and all seams caulked. Water was introduced into the tank through a garden hose behind a metal baffle in the tank. After steady state flow had been reached, the discharge for approximately 20 seconds was caught in a container. The container was weighed and the net weight of the water converted to volume. The depth of the water above the centerline of the orifice ranged from 2.5 to 3.5 hole diameters. At all times the discharge was free and unsubmerged. After steady-state flow had been reached, the nappe of the exit jet did not cling to the vertical surface of the riser section.

Theory

Steady-state flow was assumed in making all the measurements. Since the flume and return trough might contain 8 m^3 (290 ft^3) of water at any given time, it was necessary to wait 7 to 15 minutes after starting the pump and adjusting the valve before the system came to equilibrium. One example of raw data is given in Table 2 in the Appendix. It is important to note that time of 0:00 was an arbitrary point to begin recording time, probably 10 minutes after the pump was started. The riser point gauge readings remained steady from 4 minutes to 16 minutes. The flow at the weir, however, took longer to reach steady-state. It was not until the third reading that it began to stabilize. The last five readings for the riser were averaged for a data point, but only the last four weir readings were averaged. All the readings were within 0.6 mm (0.002 ft) of the average reading.

The following equation (Bos, 1976) was used to determine the flow past the 90^o V-notch sharp-crested weir.

$$Q = C_e \; 8/15 \; (2g)^{0.5} \; \tan(90^o/2) \; h_e^{2.5} \qquad (17)$$

Q - weir discharge, mm^3/s (ft^3/s)
C_e- effective weir coefficient of discharge
(see Table 4 in the Appendix for a list of C_e values)
g - acceleration of gravity, 9,810 mm/s^2
(32.2 ft/s^2)
h_e- effective weir head, mm (ft)

The effective weir head (h_e) is the sum of h_1 and k_v, where:

h_1- measured weir head, mm (ft)
k_v- notational vertical displacement of the weir, 1 mm (0.04 ft)

It should be noted that the discharge can be converted from mm^3/s to L/s by dividing by 1,000,000.

Bos (1976) lists some application limits for using the effective weir coefficients of discharge (C_e) in Equation (17). Table 3 in the Appendix shows how these limits were all met with the laboratory equipment.

RESULTS

First, the tests to determine an appropriate value for the orifice coefficient discharge are summarized below in Table 1. The conditions for these values were given in the Theory section.

Water Mass (g)	Time (s)	Head to Orifice Centerline (mm)	Orifice Coefficient of Discharge
9,359	23.0	62	0.73
10,098	25.0	61	0.73
9,717	20.9	86	0.71
10,461	22.0	90	0.71
9,825	20.7	91	0.70
10,555	22.0	93	0.70

Table 1. Orifice Coefficient of Discharge for a 25-mm (1-in) diameter hole.

Tables 5 through 7 in the Appendix show a summary of the data taken for each of the three risers. The water depths at the riser and the weir, the appropriate coefficient of discharge (Bos,1976) for the weir (C_e), and the computed discharge through the weir are included. The point gauge readings have been omitted for clarity. Again, the riser water depth was the difference between the riser point gauge reading during flow through the riser and the riser point gauge reading of the water surface when flow ceased to go through the lowest point of the bottom orifice.

Since the data from Table 1 suggests that the coefficient of discharge may differ significantly from 0.6, the depth-discharge curves were used to determine the most appropriate coefficient of discharge for the Beasley et al. (1984) Equation (9). The method used to determine this best fit was the least-squares method. Different discharge coefficients were inserted into Equation (9) and the sum of squares computed. The discharge coefficient yielding the smallest sum of squares was then chosen as the one giving the best fit for the data on each riser. Tables 8-10 in the Appendix present all the appropriate data.

One of the research objectives was to compare the data against current design criteria, so the SCS (1979) Equation (13) is included in each of Tables 8-10 in the Appendix. Note that since the SCS (1979) riser design chart was developed with a discharge coefficient of 0.6, this value was used for comparative purposes.

DISCUSSION OF RESULTS

The results of Table 1 are very significant. Both Beasley et al. (1984) and the Kansas SCS (1979) assumed the orifice coefficient of discharge to be approximately. 0.6. These data indicate that a round hole in a curved surface may have a much larger discharge coefficient, ranging from 0.70 to 0.73. The riser depth-discharge curves support this conclusion.

Table 8 in the Appendix shows the statistical results for the round-hole riser. Below riser depths of 300 mm (0.98 ft), the SCS Equation (13) underestimates the actual discharge. Above that depth, the SCS Equation (13) overestimates the riser discharge. The best-fit discharge coefficient for the data in Table 8 was 0.71. Obviously, since the discharge coefficient was derived from the data, the fit is better than the SCS Equation (13). Note how much smaller the sum of squares is for the Beasley et al. Equation (9) than for the SCS Equation (13). Still, the SCS equation estimates the riser discharge remarkably well, as shown in Figure 5. This good fit is due to two compensating errors. The first error is using a discharge coefficient of 0.6, which is too low. The second error is the extra 25% discharge built into the equation itself.

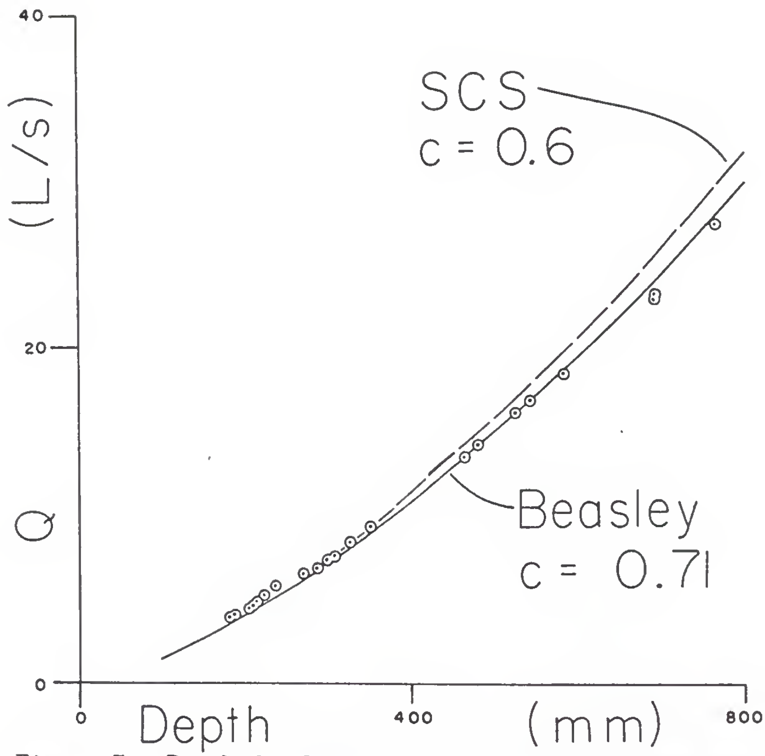


Figure 5. Depth-discharge curve for Round-Hole Riser

However, Figure 6 and the results in Table 9 show markedly different results for the slotted riser. The SCS discharge estimates are consistently high at all depths. The Beasley et al. equation accurately predicts the measured discharges very well. The best-fit discharge coefficient for the slotted riser was 0.60. This value for the discharge coefficient was much lower than for the round hole riser. However, this 0.60 value is consistent with the theoretical value of 0.61 for a slot of infinite length.

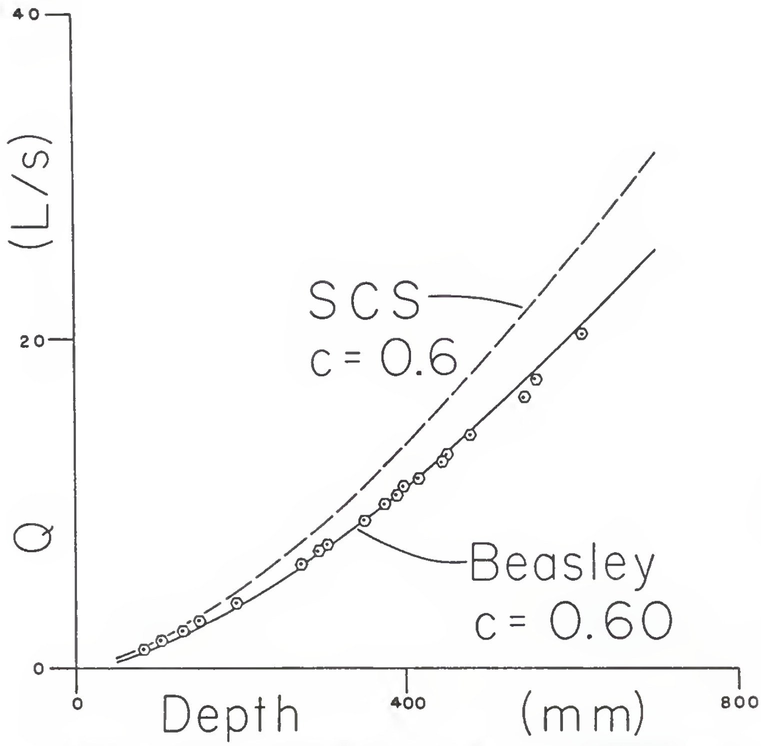


Figure 6. Depth-discharge curve for Slotted Riser

Table 10 in the Appendix and Figure 7 show the results for the Hickenbottom riser. The least-squares estimate for the Hickenbottom discharge coefficient in the Beasley et al. Equation (9) is 0.75. The SCS Equation (13) does a fairly good job of estimating the riser discharge for the Hickenbottom riser, much the same way as it did for the round-hole riser.

Only six data points were measured for the Hickenbottom riser because the weir and return trough could not handle larger flows. The fundamental predictive equations had to be altered slightly to model the discharge from the Hickenbottom riser. This riser had a "blank row of holes" at a depth of 346 mm (1.14 ft). In other words, the rows of holes were regularly spaced below this depth and above this depth. But the spacing between the fifth and sixth row of holes was double the spacing between any two other rows of holes on the riser. Since these equations all assume that the holes are equally spaced on the riser, modifications were made to account for the irregularity of the holes in the Hickenbottom riser.

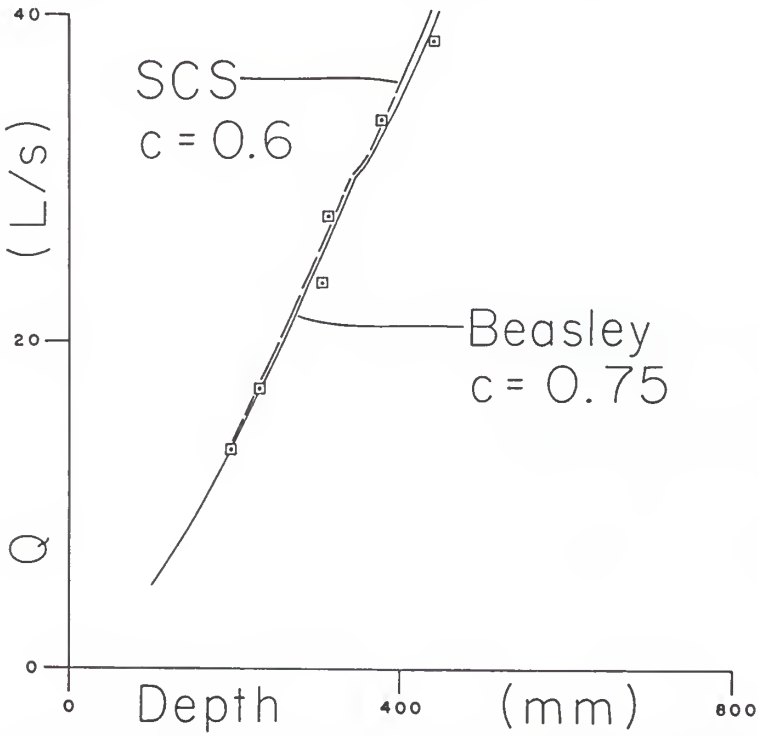


Figure 7. Depth-discharge Curve for Hickenbottom Riser

The riser discharge is computed assuming that the "blank row of holes" between the fifth and sixth row exists, then the flow from the phantom row is subtracted. The modification is only necessary at depths above 346 mm (1.14 ft).

It is important to note that the equation would be different for the Hickenbottom riser if it were installed in the field. In the laboratory, the first row of holes of Hickenbottom riser was completely covered by the PVC saddle the risers were set in. Since this row of holes would be uncovered in field installations, the depth to the centerline of the row of blank holes would be 412 mm (1.35 ft) instead of 346 mm (1.14 ft).

Another important result of the experiment was observing the flow of all the risers during operation. As one would expect, the water surface inside the riser was much lower than outside for the round-hole and slotted riser. There was only a slight difference in elevation inside and out for Hickenbottom riser. The water level inside the riser was generally not well defined for the two cast acrylic risers.

It was difficult to tell by observation if the downward flow inside the riser was aerated or submerged flow. The flow could best be described as a tumbling mass of water and air.

During testing, the top of the slotted riser seemed to vibrate laterally more than the other risers did. Continuous lateral vibrations would surely tend to weaken the riser joint prematurely. This vibration can be explained by considering how the holes are distributed on the riser. The slots on this riser did not oppose one another as on the other risers. Therefore, unequal moments were created by water entering the riser through the different slots at different heights and at different angles in plan view.

Good riser designs should include opposing perforations that are located in horizontal rings, with the perforations spaced equidistant around the ring. The "spiral staircase" design layout of the perforations on the slotted riser did not seem as stable as the others.

CONCLUSIONS

1. Orifice discharge coefficients for a 25-mm (1-in) hole were measured to be from 0.70 to 0.73.
2. The least-squares best-fit discharge coefficient for a 25-mm (1-in) diameter hole ranged from 0.71 to 0.75.
3. The least-squares best-fit discharge coefficient for the 25 x 102 mm (1 x 4 in) slots was found to be 0.60.
4. The current Kansas SCS design equation closely predicted riser discharge for the round-hole riser and the Hickenbottom riser. It did, however, overestimate riser discharge for the slotted riser.
5. The Beasley et al. (1984) equation closely predicted riser discharge for all three risers when used with appropriate discharge coefficients.
6. The most stable risers during flow had opposing holes equally distributed around the circumference of the riser.

SUGGESTIONS FOR FURTHER RESEARCH

Additional research could be used to develop appropriate discharge coefficients for different perforation types. Laboratory testing would be required for each perforation and riser diameter to determine a coefficient of discharge.

Other types of riser can be tested also. Some risers are designed with an open top. The top of the riser eventually submerges and flow over the top enters into discharge calculations.

A practical concern during field conditions is plugging of the riser with floating vegetative debris. One could examine the percentage of riser holes plugged by different types of crops and at different stages of deterioration.

A final area for research is the interaction between horizontal orifice plates and risers. In some installations, the flow going into the underground outlet pipe is restricted by an orifice plate. Again, the problem is to determine the true heads on the orifices. The water depth inside the riser will be less than the depth outside the riser, but no testing shows how much.

BIBLIOGRAPHY

Beasley, R. P., J. M. Gregory and T. R. McCarty. 1984. Erosion and sediment pollution control, 2nd ed. Ames, Iowa. Iowa State Press. p. 145.

Bos, M. G. 1976. Discharge measurement structures. Wageningen, The Netherlands. International Institute for Land Reclamation and Improvement. pp. 161-168.

Caldwell, L. W. 1985. Determination of storage requirements for underground outlet terraces in the Midwest. ASAE Paper No. 85-2544. St. Joseph, MI.

Linderman, C. L., N. P. Swanson and L. N. Mielke. 1976. Riser intake design for settling basins. Transactions of the ASAE 19(5):894-896.

Mielke, L. N. 1985. Performance of water and sediment control basins in northeastern Nebraska. Journal of Soil and Water Conservation 40(6):524-528.

U. S. Dept. of Agric., Soil Conservation Service. 1979. Discharge through perforated risers for underground outlets. Engg. Field Manual, Ks. Notice 10, Exhibit KS-8-4.

APPENDIX

Table 2. Raw Data for Round-Hole Riser

Time	Point Gauge Readings			
	Riser		Weir	
min:sec	mm	ft	mm	ft
0:00	584	1.915		
2:16			575	1.885
4:40	585	1.919		
6:07			590	1.934
7:20	585	1.919		
9:10			591	1.938
10:35	586	1.921		
11:38			591	1.940
12:30	585	1.920		
*			591	1.939
15:13	586	1.921		
16:10			591	1.940

Note: Time 0:00 is an arbitrary time to begin taking readings.
* --- Data not available

Table 3. V-Notch Weir Equation Limitations

Variable	Suggested Limits	Laboratory Values
h_1/p	<=1.2	<=0.8
h_1/B	<=0.4	<=0.3
h_1	$0.05m<h_1<0.6m$	$0.05m<h_1<0.25m$
p	>0.10m	0.3m
B	>0.60m	0.86m
Notch Angle	25^o<angle<100^o	90^o
Weir Tailwater	remains below the vertex	yes

Note: Suggested Limits from Bos (1976)

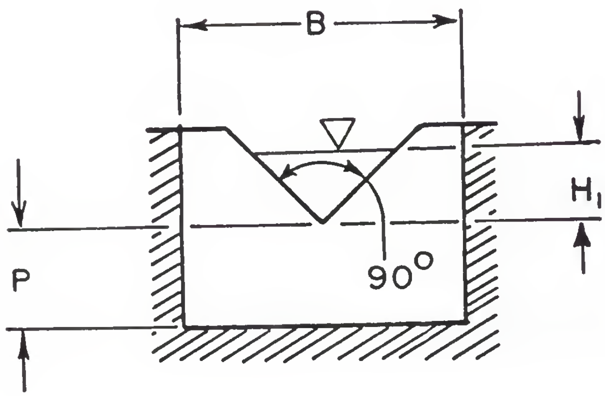


Table 4. Weir Coefficients (C_e) for Different Heads

Weir Head (mm)	Weir Head (ft)	Weir Coefficient
61	.20	.578
91	.30	.578
122	.40	.578
152	.50	.579
183	.60	.580
198	.65	.581
213	.70	.582
229	.75	.584
244	.80	.585
259	.85	.587
274	.90	.589

Note: Values taken from Bos (1976)

Table 5. Round-Hole Riser Data

Riser Depth (mm)	Weir Depth (mm)	Weir Disch. Coeff. Ce	Weir Disch. (L/s)
27	52	.578	.9
182	95	.578	3.9
187	96	.578	4.0
208	100	.578	4.4
211	102	.578	4.6
215	103	.578	4.8
223	107	.578	5.2
238	111	.578	5.7
272	117	.578	6.6
287	120	.578	6.9
301	123	.578	7.3
309	124	.578	7.6
327	130	.578	8.4
353	135	.578	9.3
466	156	.579	13.3
482	159	.579	14.1
526	168	.580	16.0
543	170	.580	16.7
584	177	.580	18.3
691	195	.581	23.3
763	208	.581	27.4

Table 6. Slotted Riser Data

Riser Depth (mm)	Weir Depth (mm)	Weir Disch. Coeff. Ce	Weir Disch. (L/s)
82	60	.578	1.2
103	67	.578	1.7
130	77	.578	2.3
159	86	.578	3.0
196	96	.578	4.0
271	115	.578	6.3
293	121	.578	7.1
305	123	.578	7.4
348	133	.579	8.9
372	138	.579	9.9
387	141	.579	10.5
395	144	.579	10.9
396	144	.579	11.0
416	146	.579	11.3
441	151	.579	12.3
447	153	.579	12.7
475	159	.579	14.0
540	170	.580	16.7
553	173	.580	17.3
610	184	.580	20.1

Table 7. Hickenbottom Riser Data

Riser Depth (mm)	Weir Depth (mm)	Weir Disch. Coeff. Ce	Weir Disch. (L/s)
197	156	.579	13.3
229	172	.580	17.0
306	195	.581	23.4
311	209	.582	27.6
376	225	.583	33.3
439	237	.584	38.2

Table 8. Round-Hole Riser Statistical Fit

Riser Depth (mm)	Weir Disch. (L/s)	SCS Disch. (L/s)	Square of Diff.	Orifice Coeff. of Disch.= 0.71 Beasley Disch. (L/s)	Square of Diff.
27	.9	.2	.49	.2	.49
182	3.9	3.4	.25	3.2	.49
187	4.0	3.6	.16	3.4	.36
208	4.4	4.2	.04	4.0	.16
211	4.5	4.3	.04	4.1	.16
215	4.8	4.4	.16	4.2	.36
223	5.2	4.7	.25	4.4	.64
238	5.7	5.2	.25	4.9	.64
272	6.5	6.3	.04	5.9	.36
287	6.8	6.8	.00	6.4	.16
301	7.4	7.3	.01	6.9	.25
309	7.5	7.6	.01	7.2	.09
327	8.5	8.3	.04	7.8	.49
353	9.3	9.3	.00	8.8	.25
466	13.4	14.1	.49	13.3	.01
482	14.0	14.8	.64	14.0	.00
526	16.1	16.9	.64	16.0	.01
543	16.6	17.7	1.21	16.7	.01
584	18.3	19.8	2.25	18.7	.16
691	23.3	25.5	4.84	24.0	.49
763	27.4	29.6	4.84	27.9	.25
		Sum of Squares	16.65	Sum of Squares	5.58

Table 9. Slotted Riser Statistical Fit

Riser Depth (mm)	Weir Discharge (L/s)	SCS Disch. (L/s)	Square of Diff.	Beasley Disch. (L/s) (Orifice Coeff. Disch. = 0.60)	Square of Diff.
82	1.2	1.3	.01	1.0	.04
103	1.7	1.8	.01	1.4	.09
130	2.3	2.5	.04	2.0	.09
159	3.0	3.4	.16	2.7	.09
196	4.0	4.6	.36	3.7	.09
271	6.3	7.5	1.44	6.0	.09
293	7.1	8.5	1.96	6.8	.09
305	7.4	9.0	2.56	7.2	.04
348	8.9	11.0	4.41	8.7	.04
372	9.9	12.1	4.84	9.7	.04
387	10.5	12.9	5.76	10.3	.04
395	10.9	13.3	5.76	10.6	.09
396	11.0	13.3	5.29	10.6	.16
416	11.3	14.3	9.00	11.4	.01
441	12.3	15.7	11.56	12.5	.04
447	12.7	16.0	10.89	12.7	.00
475	14.0	17.5	12.25	13.9	.01
540	16.7	21.2	20.25	16.9	.04
553	17.3	22.0	22.09	17.5	.04
610	20.1	25.5	29.16	20.3	.04
		Sum of Squares	147.80	Sum of Squares	1.17

Table 10. Hickenbottom Riser Statistical Fit

Riser Depth (mm)	Weir Disch. (L/s)	SCS Disch. (L/s)	Square of Diff.	Orifice Discharge Coeff.= .75 Beasley Disch. (L/s)	Square of Diff.
197	13.3	13.3	.00	13.2	.01
229	17.0	16.7	.09	16.6	.16
306	23.4	25.7	5.29	25.6	4.84
311	27.6	26.4	1.44	26.3	1.69
376	33.3	33.0	.09	32.3	1.00
439	38.2	40.5	5.29	39.4	1.44
		Sum of Squares	12.20	Sum of Squares	9.14

Figure 8. Side View of Round-Hole Riser

Figure 9. Top View of Round-Hole Riser

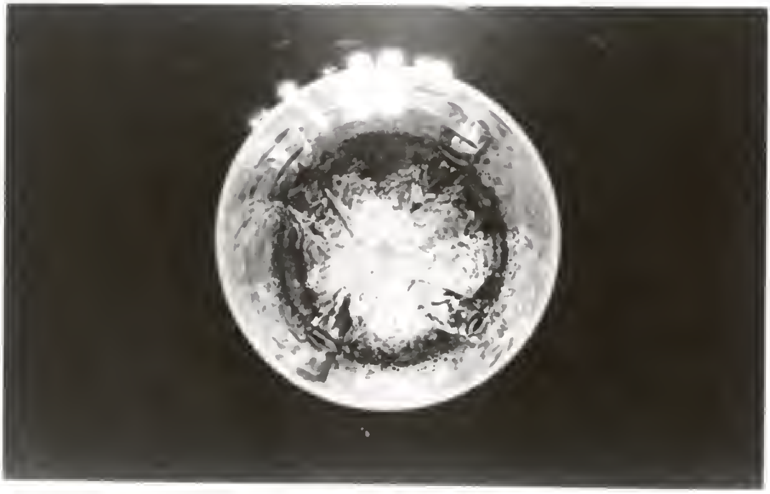


Figure 10. Side View of Slotted Riser

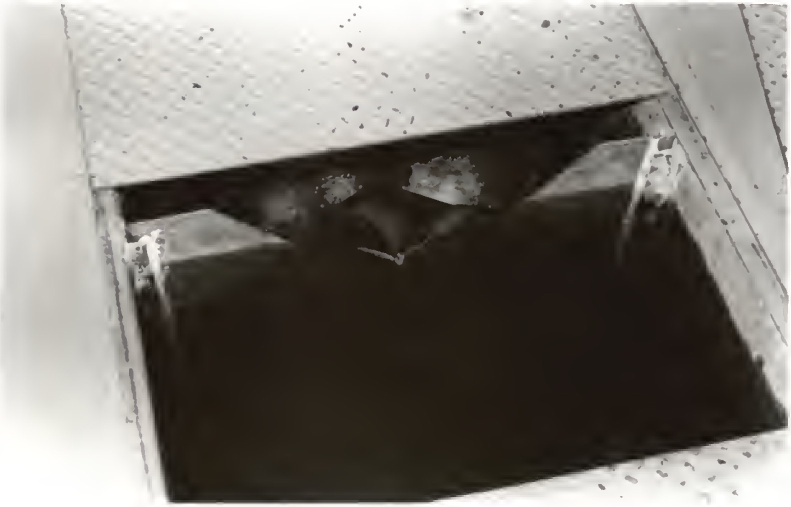
Note the riser depth gauge in the background. The flume is empty. View is looking upstream.

Figure 11. Side View of Hickenbottom Riser

Note the submerged horizontal outlet pipe and PVC saddle joint.

Figure 12. Stilling Well and Weir Depth Point Gauge

Figure 13. V-Notch Weir in Operation



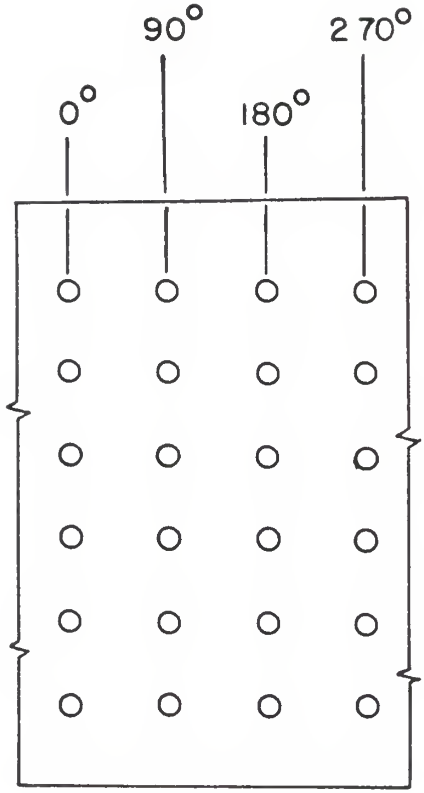


Figure 14. Round-Hole Riser Schematic

Hole diameter	25 mm	(1 in)
Centerline row spacing	102 mm	(4 in)
Holes per unit of riser height	12 holes/305 mm	(12 holes/ft)
Nominal riser diameter	150 mm	(6 in)
Total number of holes	24	

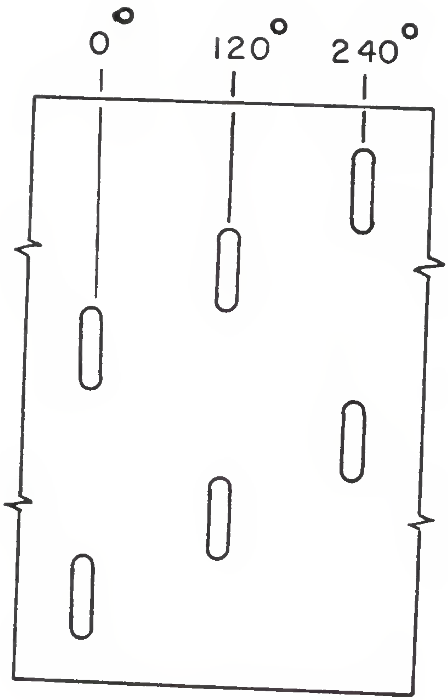


Figure 15. Slotted Riser Schematic

Slot size	25 x 102 mm	(1 x 4 in)
Vertical centerline spacing	102 mm	(4 in)
Slots per unit riser height	3 slots/305 mm	(3 slots/ft)
Nominal riser diameter	150 mm	(6 in)
Total number of slots	6	

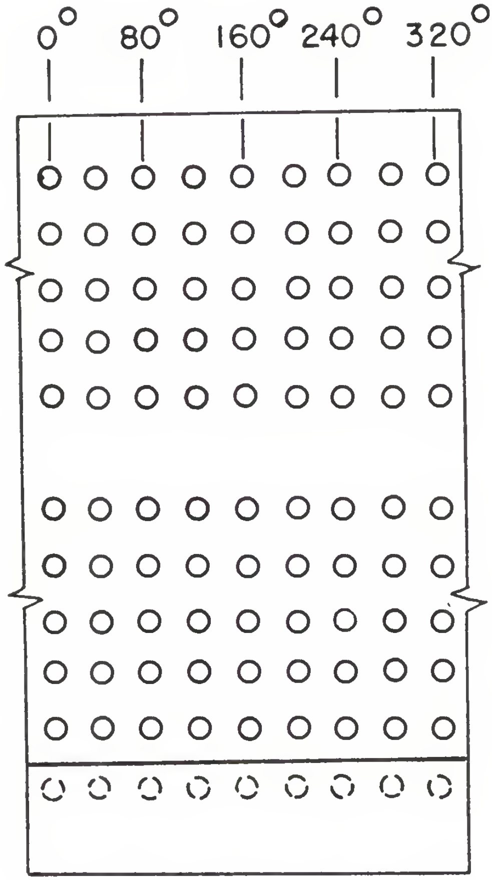


Figure 16. Hickenbottom Riser Schematic

Hole diameter	25 mm	(1 in)
Vertical centerline spacing (for the first 5 rows)	67mm	(2.6 in)
Holes per unit riser height (for the first 5 rows)	41 holes/305 mm	(41 holes/ft)

Note: The row of dashed line holes were covered up by the PVC saddle during testing.

HYDRAULICS OF PERFORATED TERRACE INLET RISERS

by

KARL KENTON VISSER

B. S., Kansas State University, 1982

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE in Agricultural Engineering

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

Abstract

Many perforated terrace inlet risers are being installed each year in the Midwest. However, little testing has been done with the intent to check the accuracy of riser design equations. The Kansas Soil Conservation Service and Beasley et al. have developed predictive equations for riser design.

The orifice discharge coefficient was measured for a 25-mm (1-in) diameter sharp-edged orifice in a section of 150-mm (6-in) cast acrylic tubing. Values of the discharge coefficient ranged from 0.70 to 0.73.

Full scale testing of three different risers was conducted using the Kansas State University hydraulic flume with slight modifications. Two risers were fabricated from clear cast acrylic and one was a commercial riser. Depth-discharge data were measured for each riser.

The experimental data were used to evaluate the SCS and Beasley equations. The SCS equation closely approximated discharge for risers with 25-mm (1-in) diameter holes. The SCS equation significantly overestimated discharge for the riser with 25 x 102 mm (1 x 4 in) oval slots. The Beasley et al. equation correctly predicted riser discharge for all three risers when an appropriate orifice discharge coefficient was used.

Apparent values of the orifice discharge coefficients were computed indirectly by fitting the Beasley equation to the experimental data using a least-squares procedure. Values of the orifice discharge coefficient ranged from 0.70 to 0.75 for the 25-mm (1-in) holes and was 0.60 for the slots. Water depths outside the risers ranged from 27 mm (0.09 ft) to 763 mm (2.50 ft).

The one riser that did not have opposing perforations located in a horizontal concentric ring seemed to slowly vibrate laterally about its fixed base. The other two risers were much more stable.